

Waste Paper Derived Biochar for Sustainable Printing Products

Staples Sustainable Innovation Laboratory Project

SSIL16-002

Final Report

Period of Performance: May 16, 2016 – December 31, 2017

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A. Executive Summary

Rationale for Research

The Golisano Institute for Sustainability (GIS) at the Rochester Institute of Technology (RIT) performed a research and development assessment in conjunction with the Staples Sustainable Innovation Laboratory (SSIL) to determine the potential of pyrolyzed waste paper as a novel, cost-effective, environmentally friendly and sustainable black pigment for use in common consumer and commercial printing applications (e.g. inkjet, lithography and flexography). To do so, the primary focus of the project was the creation and testing of a stable form of elemental carbon called “biochar” (BC) to replace the heavy fuel oil derived “carbon black” (CB) pigment ubiquitously used in inks since the late 1800’s. Reducing the use of CB would lessen the demand for fossil fuels, decrease printing’s environmental impact and potentially save money since biochars are typically created from free or low cost waste feedstocks which would ordinarily be disposed. Prior published scientific research and patents demonstrated that biochars could be successfully made from box cardboard, paper towels and glossy paper. If paper waste biochars could then be successfully transformed into a sustainable black ink pigment replacement, significant commercial potential exists since the global printing ink market is forecasted to reach \$23.8 billion by 2023 and consumers would like the option of a more ‘green’ alternative. [1]

Key Findings & Results

- A new category of sustainable black printing ink was successfully fashioned with finely ground waste paper biochar pigments. High quality images were printed from these inks using a manual letterpress at a 30% pigment loading rate (cf. according to RIT Chemistry professor Scott Williams, traditional inks have ~4-8% loading rate). Though promising, oil-based manual letterpress currently only represents a very small part of the printing market.
- The main limiting factor to the integration of biochar in the multi-billion dollar commercial flexography, lithography and ink jet markets appears to be its large average particle size (~20 μm , hand ground) compared to CB (~0.5 μm). Therefore, biochar pigment particles require additional grinding to match CB’s optical density since an inverse relationship exists between particle size and depth of black hue. Because the average cost of CB is \$4.80 kg^{-1} and BC is \$3.63 kg^{-1} , this processing cannot be more than \$1.17 kg^{-1} in order for BC to be cost equivalent to CB.
- Capturing just 1% of the \$23 billion global ink market by 2023 would represent the potential for more than \$200 million in sales. ‘Sustainable’ ink products are one of the fastest growing segments of the market. [1]

- It is estimated that the annual mixed office waste paper and cardboard flows at just one representative Staples distribution center could be converted into ~200 metric tons of biochar, sequestering ~330 metric tons of “Carbon Dioxide Equivalent” (C0_{2e}) and provide enough pigment for almost one million liters of biochar ink, assuming an 8% loading rate.
- Biochar created from this cardboard contains significant amounts of inorganic additives such as kaolin clay, titanium dioxide (TiO₂) or calcium (Ca) that would require additional processing to achieve the darkest color possible. Feedstocks should ideally contain as few impurities as possible since different chemical dispersants would theoretically be needed to remove each one.

Suggested Future Research Activities

- Continue testing cleaned waste cardboard paper pulp that cannot otherwise be recycled again, as a biochar pigment feedstock.
- Significant amounts of paper towels are returned to Staples distribution facilities in unsalable condition due to superficial packaging defects. It is believed these unused paper towels could be converted into an effectual pigment due to the lack of clay and TiO₂ containments found in waste cardboard.
- Directly measure varying amounts of direct heat and microwave energy combinations to minimize the total amount of energy and cost used to create the BCs.
- Partner with an outside cardboard flexography printing firm to imprint actual ‘Staples brand’ cardboard shipping boxes with biochar ink to demonstrate commercial potential scale up and uncover limitations of actually doing so.
- Test various proportions of biochar and CB pigments blends to see if biochar could be added to CB as a filler without reduction in performance.
- Inject biochar ink into various consumer products (e.g. pens, inked stamps, markers, felt-tip markers, etc.) and obtain qualitative feedback from potential end users.

Nomenclature

BB	bone black	BC	biochar
CB	carbon black	C0 _{2e}	carbon dioxide equivalent
GHG	greenhouse gas	GIS	Golisano Institute for Sustainability

B. Project Background

Worldwide sales of black inks used in everything from pens to inkjet print cartridges and commercial printing are projected to reach \$23 billion by 2023. [1] What gives these products their striking black color is a carbon-rich pigment called “carbon black” (CB) derived from thermal decomposition or partial (incomplete) combustion of hydrocarbon based fuels (e.g. heating oil). As such, our current method of ink manufacture used since the late 1800’s is neither sustainable nor environmentally benign since fossil fuels represent a finite resource which will eventually be depleted and whose use is the most significant contribution to climate change. [2] This necessitates a re-examination of the fundamental production of ink itself to identify and develop a more progressive approach that combines the benefits of using pre-industrial organic feedstocks with

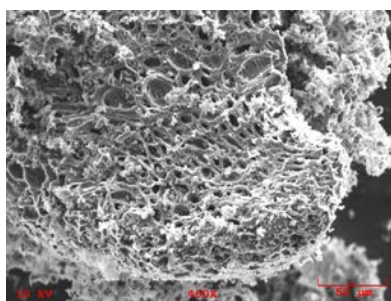


Figure 1 - Waste cherry pit biochar, 400x,
Source: author

modern material processing technologies to enable use in today’s more complex printing devices. One such potential alternative is to create black pigments derived from renewable biomass or biomass-based products that don’t use fossil fuels as their feedstock but replicate all the key physical properties (e.g. particle size, hue, durability, etc.) of CB. A promising example of this is “biochar” (BC), the end product of thermochemical conversion of renewable or waste biomass (carbon rich organic substances, the original precursors to fossil fuels themselves) to charcoal in the absence of oxygen at temperatures of 250°C or greater (i.e. ‘pyrolysis’). Generally speaking, BC is considered charcoal that was intentionally created to sequester CO₂, used as a soil amendment and obtains its black color from having a C content >80% (Figure 1). Prior work at RIT’s Golisano Institute for Sustainability’s (GIS) thermochemical conversion laboratory has demonstrated that the ultimate properties of BC (particle size, surface area, porosity, etc.) can be carefully controlled by selection of the raw feedstock material and pyrolysis conditions (e.g. temperature, heating rate, choice of inert gas, etc.). It was therefore hypothesized that the desirable qualities of CB for inks could possibly be replicated through a series of systematic trial and error experimentations. Creating a more sustainable ink by changing its pigment (i.e. what makes the black in black ink actually ‘black’) rather than it’s carrier takes a fundamentally different tack from current suite of ‘green ink’ offerings which derive their claim to sustainability from containing soy-based drying agents with no volatile organic compounds (VOCs) or contained in remanufactured print cartridges (Figure 2). Though most prior work in the BC field has focused on agricultural residues as primary feedstocks (i.e. corn stover, cow manure poultry litter, etc.) for use as a soil amendment,



Figure 2 – Staples Sustainable Earth
Remanufactured Toner Cartridge

recently publications and patents indicate that printing paper and cardboard can produce BCs with very favorable and consistent properties [3,4]. For an office supply firm like Staples which itself generates large quantities of cardboard and paper wastes on a daily basis, the potential to convert these materials into saleable value-added products while sequestering CO₂ represents a compelling opportunity to move toward a “circular economy” model that is both environmental and shareholder friendly. Simply put, it is postulated that modern day paper and cardboard BC could be the modern day equivalent of pre-industrial CB with contemporary grinding and functionalization treatments and given the large volume of paper and cardboard generated and disposed of each year. Based on the initial literature review and leveraging our existing research in BCs derived from commercial food wastes, the project was structured around five Tasks with the ultimate goal to produce a commercially viable “biochar ink”.

C. Summary of Task 1 Activities and Outcomes (History of Carbon Black & Paper Biochar Literature Review)

- *Task 1: Report of a comprehensive literature review of biochar materials derived from paper or other cellulose-based products, and the technical details, specifications and processes involved in formulating conventional black inks. This review will be combined with the results of a survey of waste paper materials typically available at large Staples product facilities. (end of Task 2, Month 3)*

a. History and Development of Carbon Black as an Ink Pigment

Before testing the working hypothesis that BC could be a sustainable and cost effective replacement for CB pigments in printing inks, a comprehensive narrative literature review was performed to understand the definitions of CB and its history and context in printing applications.

Definitions of Carbon Black:

1. According to Spokas, CB is considered a “combustion condensate” or “Forms of black carbon that contain no relic structures of the parent biomass material. Typically, these forms of black carbon have oxygen to carbon ratios (O:C) of less than 0.2, comprised of soot and graphite.” [5]
2. Lehmann and Joseph refer to CB or Black Carbon as “PCMs (Pyrogenic Carbonaceous Materials) dispersed in the environment from wildfires and fossil fuel combustion.” [6]

3. Sid Richardson Corporation (the largest manufacturer of CB in the U.S.) defines CB as “an engineered material, primarily composed of elemental carbon, obtained from the partial combustion or thermal decomposition of hydrocarbons, existing as aggregates of aciniform morphology which are composed of spheroidal primary particles, uniformity of primary particle sizes within a given aggregate, and turbostratic layering within the primary particles” (Figure 3). [7]



Figure 3 – Representative carbon black by Sid Richardson used to create synthetic HP 61 ink

4. International Carbon Black Association (ICBA) defines carbon black as “a virtually pure elemental carbon in the form of colloidal particles that are produced by incomplete combustion or thermal decomposition of gaseous or liquid hydrocarbons under controlled conditions.” It is “black, finely divided pellet or powder” and its use “in tires, rubber and plastic products, printing inks and coatings is related to properties of specific surface area, particle size and structure, conductivity and color.” [8]

Before the discovery of fossil fuels, a form of CB called ‘lamp black’ was manufactured in a process involving a ‘sac a noir’ whereby lamp oil or fats were left to smolder in a relatively oxygen free closed deerskin tent and then beaten to dislodge the soot and collected (Figure 4). [9] This method changed significantly at the end of the 19th and early 20th centuries with the use of heavy oil as a feedstock in large steel vessels. The primary use of modern day CB was to reinforce and strengthen rubber used in tire manufacturing. According to Sid Richardson, a leading manufacturer of CB in the U.S., CB used for ink pigments today are created by the “furnace black process” which vaporizes, pyrolyzes and atomizes heavy fuel oil in a large closed reactor under carefully controlled temperature and pressure conditions to form microscopic carbon particles. [7] The newly formed CB is then quenched, cooled, filtered and collected in large bags in a continuous process (Figure 5).

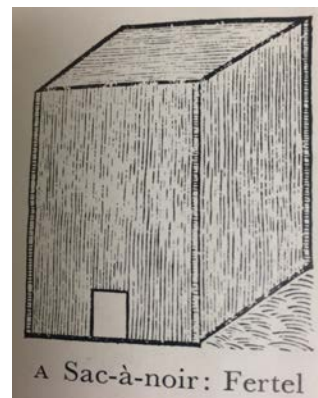


Figure 4 - Deerskin “sac-a-noir” tent used to make pre-industrial carbon black, England, 1700’s [9]

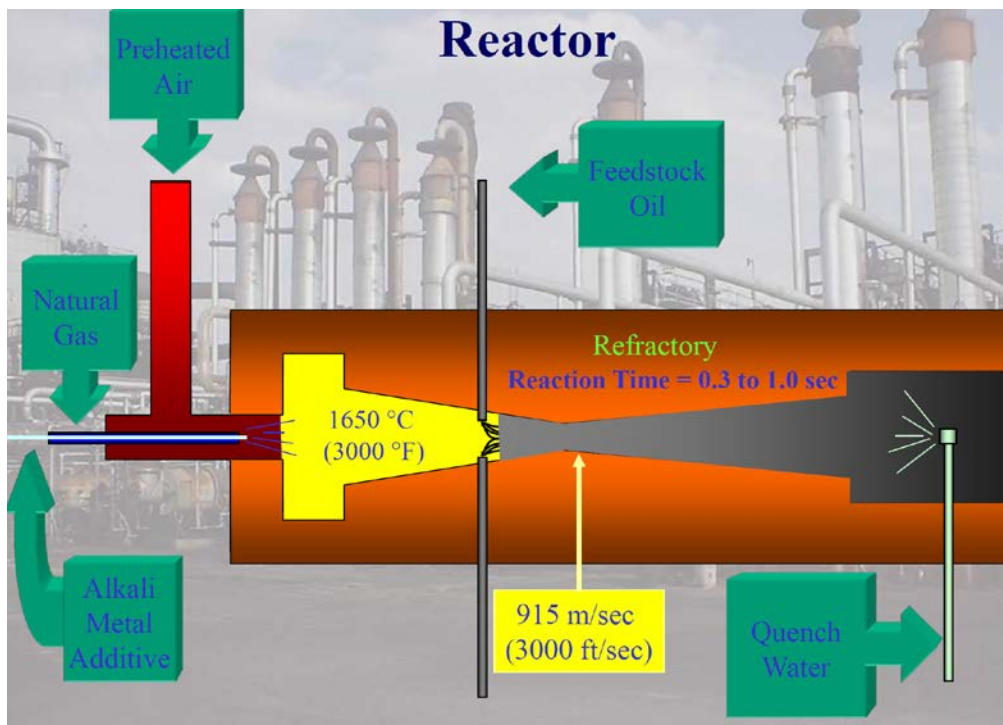


Figure 5 – Modern “furnace black” process, Source: Sid Richardson [7]

b. Definitions, History and Current Uses of Biochar

As with CB, a comprehensive narrative literature review was performed to understand the definition, history and current uses of BC.

Definitions of BC:

1. According to the International Biochar Initiative (IBI), BC is “a solid material obtained from thermochemical conversion of biomass in an oxygen-limited environment . . . can be used as a product itself or as an ingredient within a blended product, with a range of applications as an agent for soil improvement, improved resource use efficiency, remediation and/or protection against particular environmental pollution and as an avenue for greenhouse gas (GHG) mitigation.” [10]
2. Additionally, the IBI regards BC as “...a solid material obtained from the carbonization of biomass. Biochar may be added to soils with the intention to improve soil functions and to reduce emissions from biomass that would otherwise naturally degrade to greenhouse gases. Biochar also has appreciable carbon sequestration value. These properties are measureable and verifiable in a characterization scheme, or in a carbon emission offset protocol.” [11]

3. Schmidt and Wilson define BC as a “black charcoal like substance discussed so often in recent days for its miraculous effects on soil and compost . . . and can be integrated into new organic systems for farming, building, clothing, electronics and a whole range of consumer products.” [12]
4. According to Merriam-Webster dictionary, BC is “a form of charcoal that is produced by exposing organic waste matter (such as wood chips, crop residue, or manure) to heat in a low-oxygen environment and that is used especially as a soil amendment” [13]

It was only recently that the term “biochar” (a blend of terms biomass and charcoal) came to use. [6] The precursor terms to biochar, “terra preta” or “black earth” were first

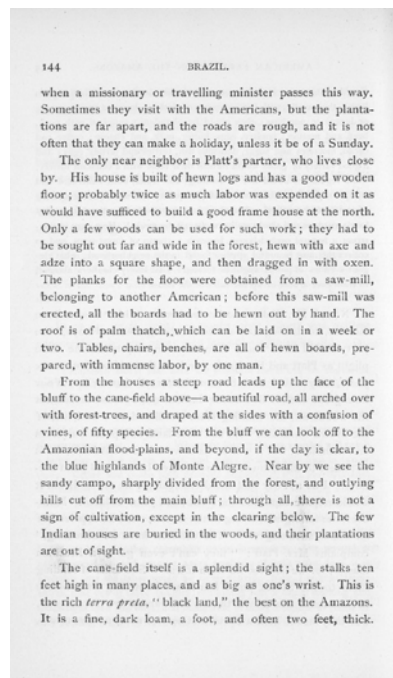


Figure 9 – The first written reference to terra preta (biochar) [14]

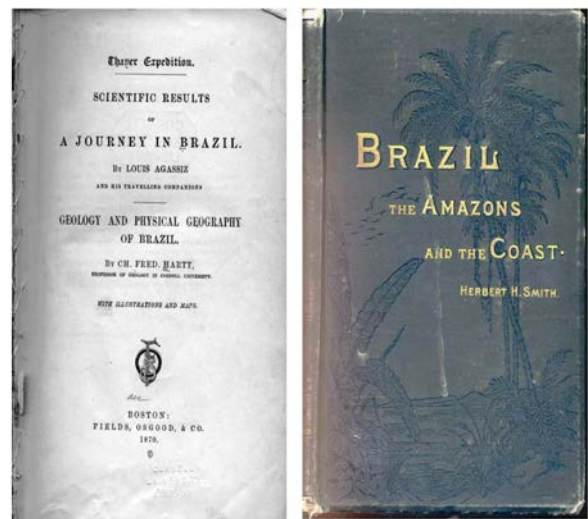


Figure 6 – “Brazil, the Amazons and the Coast” Smith, 1879 [14]

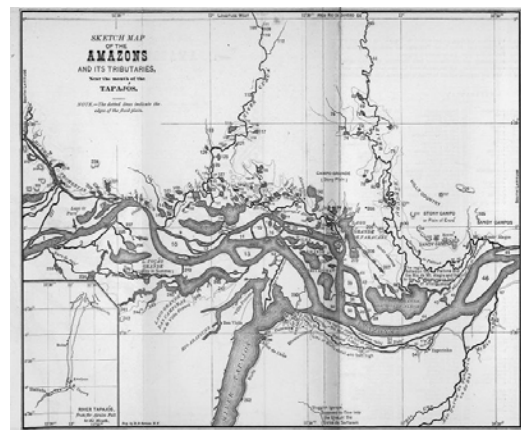


Figure 7 – The original discovery site of terra preta (biochar) [14]

mentioned by Herbert Smith in his 1879 seminal treatise “Brazil, the Amazons and the Coast”. Here Smith

noted how rainforest soils are normally nutrient deprived and



Figure 8 – “Biochar” U.S. internet word cloud, 12/2016, Source: Tagxedo.com

unproductive but those containing high levels of ancient man-made BC were much more productive (Figs. 7-8). [14] Despite efforts by archaeologists, the exact method used to create terra preta by these indigenous peoples is still unknown. Though intriguing at the time, terra preta was mostly overlooked until a century later in the early 1980's when the term 'biomass char' was conceived during research into gasification technologies as a consequence of the oil shocks of the 1970's. [15] The term 'biochar' was first coined in the mid 1990's and is a portmanteau of the words biomass and char which signifies the original BC feedstock is natural and not man made, an important distinction. Since then, BC has generally been regarded as a soil amendment thanks to the considerable amount of research performed by Cornell University's Soil Sciences department in Ithaca, NY. A U.S. internet word cloud snapshot of the term "biochar" and its associations corroborates this (Figure 8). Only very recently has BC been considered for use in other functions. The most prominent of these is as a low-cost alternative to activated charcoal for the adsorption of heavy metal ions from industrial wastewaters. [16]

c. Literature Review of Biochar as a Replacement for Carbon Black Ink Pigments

A comprehensive narrative literature review was performed to understand if BC or comparable material such as charcoal, activated charcoal, activated carbon, char or black carbon has been used as an ink pigment in lieu of CB in modern times. Besides 'lamp black' described above, the review indicated that "bone black" (BB) was very commonly used in pre-industrial painting made from finely ground bone BC and formed a durable black pigment. [17] The main difference between lamp black and BB is that lamp black was derived from emulsified animal fats and BB from solid material. The closest direct use of 'solid derived' BC as a replacement for CB in modern times was described in "Birchwood Biochar as Partial Carbon Black Replacement in Styrene-Butadiene Rubber Composites" by Peterson, et al. (2015) and "Novel Mineral and Organic Materials from Agro-Industrial Residues as Fillers for Natural Rubber" by Barrera and Cornish (2015). [18,19] The authors found that BCs from organic waste materials (eggshells, carbon fly ash, processing tomato peels and guayule bagasse) could successfully be used as filler for certain rubber composites and theoretically could displace a large percentage of CB in their manufacture. This concept of blending CB and BC in different proportions for an optimal balance of quality, sustainability and cost could be directly applicable to ink production. Interestingly, the particle size determined by Peterson et al. necessary to augment rubber products is essentially the same ($<0.5\mu\text{m}$) as needed to easily pass the filters found in modern ink jet printer cartridges. Even though these filter apertures are typically $10\mu\text{m}$ in diameter (Figure 10), they can easily get clogged if particles agglomerate to form larger clusters.

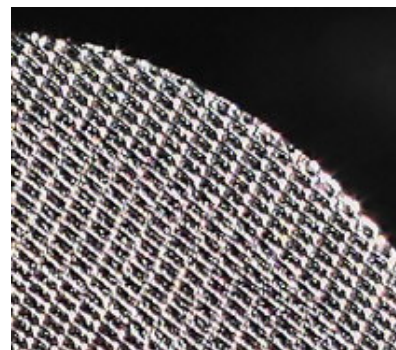


Figure 10 – Inkjet filter, $10\mu\text{m}$ aperture [20]

D. Summary of Task 2 Activities and Outcomes (Waste Paper Materials Survey)

- *Task 2: “Conduct a survey of waste paper materials (boxes, cardboard, copy paper, labels, etc.) typically available at large Staples product distribution and retail facilities. This activity will include on-site audits at Staples facilities in the greater Rochester, NY region”.*

a. Waste Paper Survey- Staples Distribution Center

A survey of waste paper materials was performed at a Staples distribution center. Three types of potential feedstocks were identified: 1) mixed office paper, 2) corrugated cardboard containers, and 3) register tape. Samples of the mixed office paper (Figure 12) and used corrugated cardboard containers (Figure 13) were collected, whereas register tape was unavailable at the time of visit so it was not obtained. According to the facilities manager, surprising amounts of paper towels are also available since significant amounts



Figure 12 – Waste office paper, Staples distribution center



Figure 11 – Waste cardboard, Staples distribution center

are returned due to packaging breaks or in transit water damage. The

estimated total mass of BC available to be created on an annual basis was calculated based on work previously performed on paper wastes in the literature. With an average 43% and 31% recovery of corrugated cardboard and mixed office paper respectively at 500°C, it is projected that $> 100,000$ kg of this blended BC could be created from the recycled paper waste generated annually at just one distribution center. [21] Given that a typical black inkjet ink is comprised of 4-8% pigment per volume, the pigment for more than one million liters of ink could theoretically be created. Since standard inkjet cartridges contain 10ml of ink (and there are 100 10ml units per L), potentially 0.8×10^9 to 1.6×10^9 10 ml ink jet cartridges could be filled. [20]

E. Summary of Task 3 Activities and Outcomes (Paper-Based Biochar Feedstock Characterization)

- Task 3: “Based on the outcomes of Tasks 1 and 2, identify three promising paper-based feedstocks that will be assessed for biochar production. Each material shall be tested in a parametric study of thermochemical conversion, including variation of maximum temperature, heating rate, heating time and oxygen content, as well as post-process grinding. Each resulting sample shall be characterized using an in-house scanning electron microscope (SEM) and BET adsorption device to measure surface morphology and composition, surface area, porosity and pore size distribution.”

a. Cardboard, office copy paper and surplus currency

The cardboard and office copy paper samples collected in Task 2 were selected as the most promising feedstocks available from the Montgomery, NY Staples facility due to the large quantity available and estimated low O:C ratio (an indicator of a BCs ‘recalcitrance’ or longevity). These samples were then ground and homogenized in an aerated hammer mill provided by Schutte-Buffalo Hammermill, LLC in Buffalo, NY (Figure 14) to reduce the feedstock’s effective particle size before pyrolysis (Figure 15). In addition, well shredded surplus U.S. currency that otherwise would have been landfilled was provided by the Federal Reserve Bank of Atlanta and used as a control due to its high quality made from virgin feedstock. All three were then pyrolysed in GIS’s Microwave Assist Technology (MAT) 1700°C inert (nitrogen) gas kiln at temperatures ranging between 500 °C and 1600 °C with and without microwave energy between



Figure 14 – Staples waste copy paper prepared for pyrolysis by hammermill pulverization & aeration



Figure 13 - Hammer mill grinding of Staples cardboard waste

0-3.99Ghz. 500°C was chosen as the minimum processing temperature, as studies have shown above this temperature potential health impacts associated polycyclic aromatic hydrocarbon (PAH) content in BC can be minimized [22]. 500°C is also the temperature at which all lignin, cellulose and hemicellulose are converted to “pyrogenic amorphous char” and acquire a deeper black appearance (Figure 15). On the other hand, CB is almost entirely comprised of orderly “turbostratic” crystalline structures formed above 700°C. When feasible, BC was processed at as high a temperature as possible to replicate this structure,

though it is still unknown if pigment quality is related to crystalline structure itself. What is well known is that the BCs black hue darkened as processing temperature increased as a result of volatiles (primarily H, C and O compounds) being driven off (Figure 15). [23]

Microwave radiation assist was included to evaluate if there was any beneficial effect of microwave compared with traditional direct heating on the pigment quality. With RIT's unique Microwave Assist Technology (MAT) kiln (one of just four in the world) it was

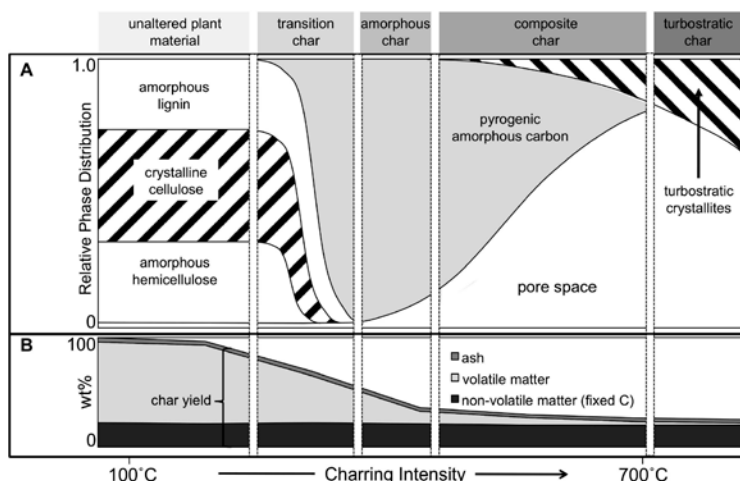


Figure 15 – Physical, chemical and molecular structure characteristics of charcoal across a charring temperature gradient [16]

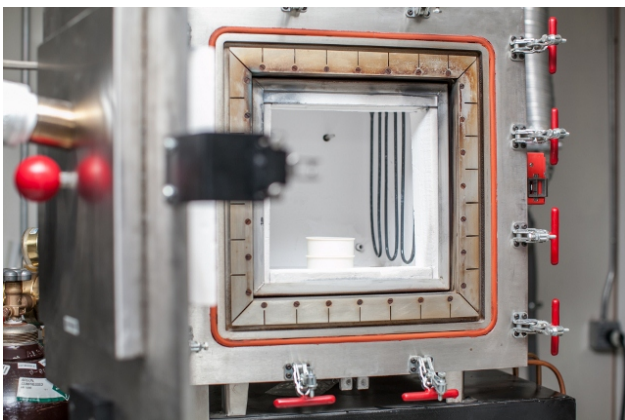


Figure 17 - RIT's Microwave Assist Technology -1700 °C Inert Atmosphere Controlled Kiln

possible to heat the material directly as in a conventional oven, just with microwave energy or with any combination of both (Figure). Repeated tests showed that microwave treatment appeared not to have any advantageous effect on pigment structure or color compared with direct heating, but studies have shown the potential to make the whole process more efficient in terms of energy input, especially with high moisture content feedstocks. [24] In future studies, the actual amount of energy use will be measured with a data logger to determine which combination of direct heat and microwave energy would be optimal for a particular feedstock. The only negative issue encountered with the microwave treatment encountered was an esoteric chemical reduction reaction of alumina to aluminum caused by high levels of carbon while using the standard microwave 'high alumina' crucibles at temperatures above 700°C. This resulted in aluminum contamination of the BC (Figure 16) that were confirmed via SEM XRF (Figure 35, Appendix C (SEM Images and X-ray Fluorescence (XRF) Analyses). After this, use of alumina crucibles and high

amount of energy use will be measured with a data logger to determine which combination of direct heat and microwave energy would be optimal for a particular feedstock. The only negative issue encountered with the microwave treatment encountered was an esoteric chemical reduction reaction of alumina to aluminum caused by high levels of carbon while using the standard microwave 'high alumina' crucibles at temperatures above 700°C. This resulted in aluminum contamination of the BC (Figure 16) that were confirmed via SEM XRF (Figure 35, Appendix C (SEM Images and X-ray Fluorescence (XRF) Analyses). After this, use of alumina crucibles and high



Figure 16 – Aluminum reduced from alumina crucibles during microwave heating

microwave heating was discontinued in favor of traditional ceramic crucibles with direct heating. It was subsequently discovered that such contamination problems can be avoided in future studies by using non-reactive zirconium oxide vessels. Since it was previously determined from the literature review that varying the inert (nitrogen) gas flow had no effect on BC product yield, this was set at a fixed flow rate of $100 \text{ cm}^3 \text{ min}^{-1}$ for all experiments (Figure 17).

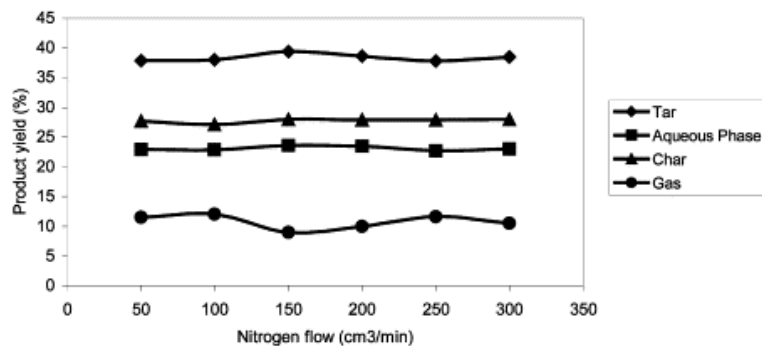


Figure 17 – Biochar yield as a function of nitrogen gas flow [25]

Post processing, surface area and pore size tests were completed utilizing a Quantachrome NOVA 4000e N_2 surface area analyzer. These results indicated a positive relationship between surface area and processing temperature. The BCs physiochemical properties were also examined pre- and post-carbonization using an x-ray fluorescence spectroscopy scanning electron microscope (SEM-XRF). The SEM-XRF images and corresponding elemental analysis are presented in “Appendix C (SEM Images and X-ray Fluorescence (XRF) Analyses)”. In addition to SEM-XRF, the BCs were also evaluated using some of the qualification standards put forth by the International Biochar Initiative (IBI), the official global BC industry group (Figure 18). One of these tests involves measuring each of the BCs relative ratio of O:C and H:C atoms. [26] Cornell University researchers determined these atomic ratios can reliably measure the “recalcitrance” or length of time a particular BC can sequester carbon before returning to atmospheric form. A recent study looked at the 115 day C^{13} degradation rate of paper and cardboard BCs produced at various temperatures and found a positive relationship between temperature and length of recalcitrance (Figure 19). Based on results from Bai et al. the paper and cardboard BCs created in this study should have low O:C and H:C atomic ratios due to O and H being driven off at increasing temperature (Figure 20) and were subsequently confirmed by SEM XRF (Appendix C (SEM Images and X-ray Fluorescence (XRF) Analyses). [26]

TABLE 1. Test Category A test methods

Test Category A: Basic Biochar Utility Properties - Required for All Biochars	
Parameter	Test Method
Moisture	ASTM D1762-84 Standard Test Method for Chemical Analysis of Wood Charcoal (specify measurement date with respect to time from production)
Organic Carbon	Total C and H analysis by dry combustion-IR detection. Inorganic C analysis by determination of CO_2 -C content with 1N HCl, as outlined in ASTM D4373 Standard Test Method for Rapid Determination of Carbonate Content of Soils. Organic C calculated as Total C – Inorganic C.
H:C _{org}	
Total Ash	ASTM D1762-84 Standard Test Method for Chemical Analysis of Wood Charcoal
Total Nitrogen	Dry combustion-IR detection following the same procedure for total C and H above.

Figure 18 – Standard International Biochar Initiative (IBI) accepted biochar tests

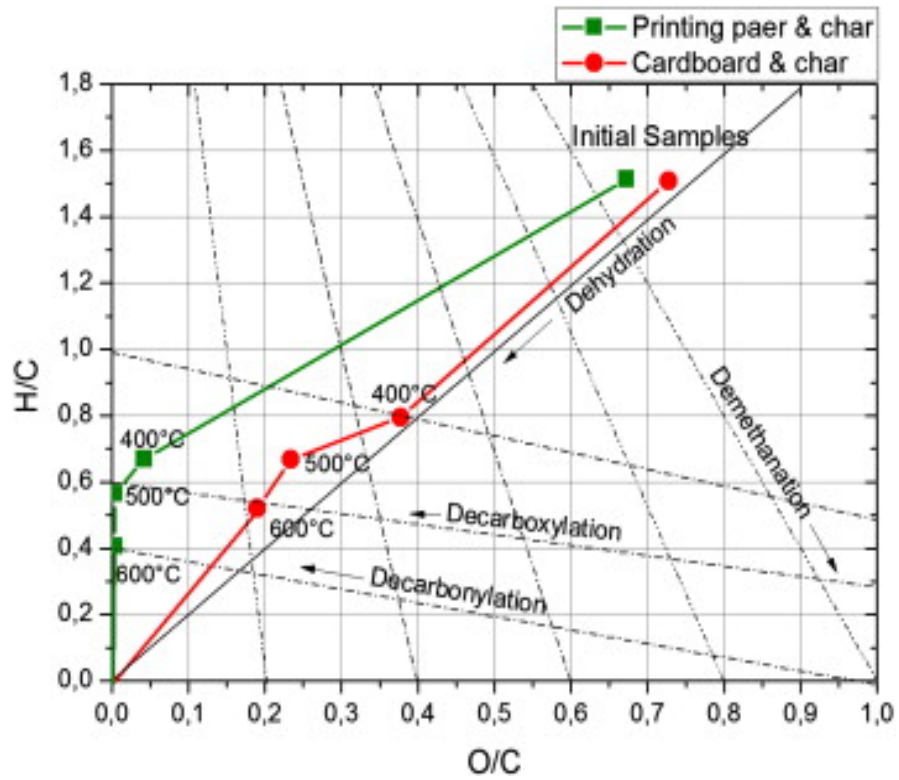


Figure 19 – O/C to H/C Van Krevelan diagram for biochars made from office paper and used cardboard [21]

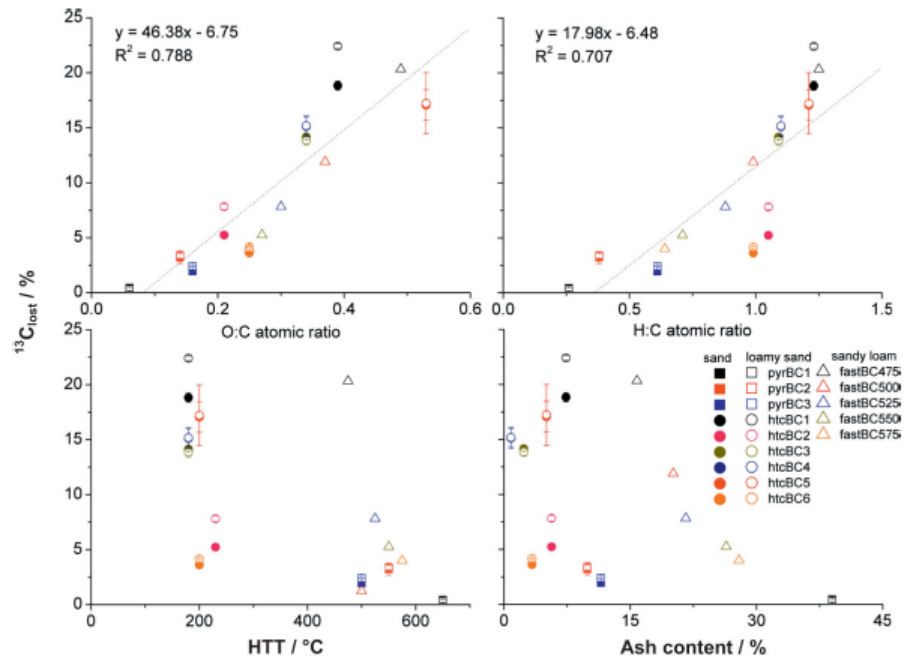


Figure 20 – Rate of carbon degradation in waste paper and cardboard BCs [26]

F. Summary of Task 4 Activities and Outcomes (Biochar Selection, Ink Formulation and Characterization)

- *Task 4: From the results of Task 3, select one specific biochar material as the “best” potential replacement for conventional carbon black, and this material will be used to formulate a sustainable biochar-based sustainable ink. The ink will be characterized in regards to its performance and durability, based on established test protocols and standards used in the printing industry (end of Task 4, Month 14).*

a. HP61 Ink Preparation

Originally, HP61 ink jet ink (Figure 22) was selected as an appropriate ‘consumer products’ benchmark from which to compare BC ink since HP61 is the best-selling ink on Amazon.com (as of July 1st 2016). Correspondingly, the ‘HP 4500 Envy all-in-one printer’ is the most popular home and small office printer (Figure 23) and was selected to perform these BC/HP61 comparative print tests. Before a BC ink could be formulated and injected into blank HP61 cartridges, HP61 itself was first characterized for surface area and zeta potential (i.e. ability of the CB particles to resist agglomeration) to understand its physiochemical properties (Figure 28-35). Based on this, RIT Chemistry and Materials Science professor Scott Williams and his research



Figure 22 – HP 61 black inkjet ink cartridge



Figure 23 – HP 61 compatible HP 4500 Envy 4500 all-in-one printer

team first set about to formulate a synthetic HP61 ink using three standard CB ink pigments: 1) (Sid Richardson) SR201, 2) SR159 and 3) Cabot BP2000 CB. These pigments were themselves tested with standard dispersants by placing a small amount of CB on a glass plate, adding a drop of dispersant and qualitatively observing if it was adsorbed or rolled off (Table 1). According to Breese, absorbency is one the most important factors to successful ink production since “[CB] Particles tend to agglomerate due to the attractive van der Waals dispersion force that becomes very strong when particles approach each other closely. A dispersant acts by preventing particles from coming into close contact, thereby reducing the tendency towards particle agglomeration.” [27] Based on these tests, the SR201 CB pigment was successfully formulated into a water-based ink with a $<0.45\mu\text{m}$ particle size at a 3%



Figure 21 – RIT logo test print using SR201 formulated CB pigment with Dimatx inkjet printer

<i>Dispersant</i>	<i>Carbon Black SR159</i>	<i>Carbon Black SR201</i>
	<i>Adsorb?</i>	<i>Adsorb?</i>
Brij 30	Yes	No
Niaproof	Yes	Yes
TWEEN 85	No	No
Triton X-114	No	No
Brij 35	Yes	Yes
Sodium dodecyl sulfate	Yes	Yes
Soap	Yes	Yes

Table 1 – Dispersant testing for synthetic HP61 ink

experimental process from which the BC pigments were subsequently created.

pigment load. Prints were made on common uncoated resume paper using a Fuji Dimatix inkjet printer with a 10 μ m nozzle refillable cartridge (Figure 21), (Appendix D (Additional Print Images)). This process of formulating raw CB to an actual ink helped establish the

b. Biochar Ink Preparation- Initial Functionalization

Similarly to CB, BC often exhibits a hydrophobic or non-dispersive surface chemistry. To create a hydrophilic (i.e. dispersive) BC that could be dispersed properly into water-based solutions, surface functionalization treatments were required. The special challenges are that the same depth of knowledge of what method works best to functionalize a particular CB simply does not exist for BC, and that BCs likely contain unknown impurities (e.g., clays, calcium carbonate, Al, Si, etc.) that need special dispersive treatments of their own. Some examples of these methods are the addition of polar functional groups such as hydroxides, nitrates and phosphates, pure oxidation or a blended approach of both. Based on a series of iterative empirical tests, a two-step hybrid functionalization procedure was used for all the cardboard, waste paper and currency BCs in this study. The first was an acid digestion step to remove light-colored mineral contaminants, followed by a chemical peroxide surface oxidation treatment. This was performed by milling the BC to a fine powder using a standard benchtop grinder, then dispersion in 1M phosphoric acid, and digested (dissolved) while stirring for one hour at 70°C. Afterwards, heat was removed and the suspension was mixed at ambient room temperature for an additional 24 hours. This long-term room temperature digestion solubilized the mineral impurities which were then filtered and washed using deionized (DI) water. The BC was then separated via freeze drying, analyzed for purity and further functionalized with a 30% (w/w) hydrogen peroxide solution and refluxed for 24 hours at 60°C. The excess hydrogen peroxide was removed by dialysis against DI water in tubing until no remaining peroxide was detected by KI oxidation test strips. The final functionalized powder was then freeze dried again and analyzed by SEM EDS to help gauge the extent of surface modification.



Figure 24 – BC pigment functionalization tests

c. Biochar Ink Preparation- Formulating a Water-based Ink

To create an actual ink jet or flexo cardboard water-based ink (all consumer ink jet and most flexo inks are water, rather than oil based), this functionalized BC was further ground using a ceramic media ball mill for 20 minutes at high speed until a mean particle size of less than $10\mu\text{m}$ by SEM observation was achieved. Afterwards, a 1% (w/w) Triton-X100 in 1% (w/w) ammonia-water solution (dispersant) was introduced (in the same container) until the final BC solid content of 30% (w/w) was achieved. This suspension was gently homogenized by tumbling at low speed for 24 hours in order to minimize foam formation. The ink preparation was finished by adding water-soluble polymers (e.g. polyacrylates, polyvinyl alcohol, and polyvinylpyrrolidone). Final ink dispersion was qualitatively measured using a NIPRI gauge (ASTM D1210), and covering power was determined using an ink draw down method with a standard 3NT-1 Leneta pad (Figure 25).

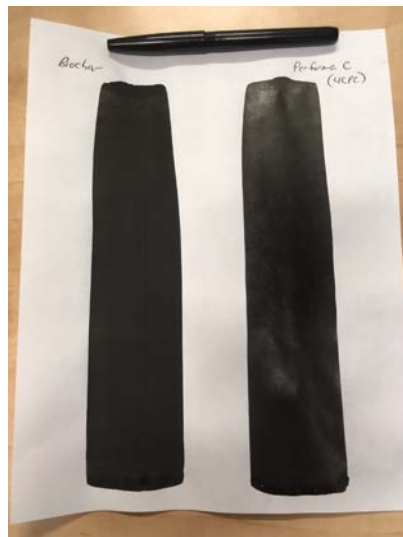


Figure 25 – Drawdown test comparing 30% currency pigment water based flexo ink (left) with a standard 8% CB flexo ink (right).

d. Biochar Ink Preparation- Formulating an Oil-Based Ink

In addition to water-based, (linseed) oil-based BC inks were also prepared to create a black ink that could for newsprint or letterpress. As mentioned earlier, it was discovered that BC surfaces are hydrophobic (water repelling), but that also means they are oil accepting. Therefore, BCs in general do not need functionalization for oil-based inks in the same sense as for water-based inks. In some cases however, the phosphoric acid purification step may be necessary to remove mineral contaminants. For this study, BC for letterpress offset ink was prepared by dispersing the BC in Damar resin using a mortar and pestle until a thick paste was achieved. ‘Stand oil’ (i.e. processed linseed oil) was then used to letdown until a final pigment concentration of about 30% (w/w) was obtained. Dryers, such as cobalt, manganese and zinc salts (or combination thereof), may be added in concentrations of $<1\%$. As with the water-based ink, dispersion was qualitatively measured using a NIPRI gauge (ASTM D1210), and covering power was determined using an ink draw down method with a standard 3NT-1 Leneta pad (Figure 25).



Figure 26 – Oil based currency BC ink (30% loading) handpress image

e. Biochar Ink Preparation- Choosing the “Best” Feedstock

BC from the surplus currency processed at 1600°C without microwave treatment was considered the “best” of the three waste paper feedstocks tested as a potential replacement for conventional CB. This is due to its relative lack of impurities, ease of functionalization and very dark hue at high loading in oil based solutions (Figure 26). Its main weakness (as with the others) was its large particle size. This hindered its performance in the water-based flexography tests as a buildup of pigment deposits was observed along the edges when the Harper proof test (scraping along paper, used as a proxy test for flexo) was performed (Figure 27). The result was larger pigment particles being pushed aside and leaving a less than ideal greyish hue. This technical hurdle is the most important to overcome since recent growth in printing applications is mostly in water-based inks for flexo packaging rather than oil based inks for newsprint. As mentioned in [Task 2](#), this is sought to be overcome by having the BC as finely ground as possible to $< 0.5\mu\text{m}$ with an outside firm then functionalized, prepared in water-base and retested. It is hoped performing this will enable water-based BC pigment inks to truly be competitive with CB pigment inks for most modern printing applications.

After much consideration, however, it was decided that if the limiting factor in making a biochar ink was particle size and not necessarily the imperfections found in a given feedstock, then the most sustainable option was to create BC from Staples cardboard that could not be recycled any further (i.e. cardboard can only be recycled approximately 7 times before needing to be disposed of) due to its availability in abundance and the fact that it is landfilled with no other use. [28] In other words, it does not make sense to prevent a waste paper that could be recycled from being recycled. Therefore, if only one BC could be ground as finely as mechanically possible and retested as originally intended at RIT’s Print and Materials Analysis Lab (Appendix E (PMAL Ink Testing)), then it should be this non-recyclable waste cardboard pulp.

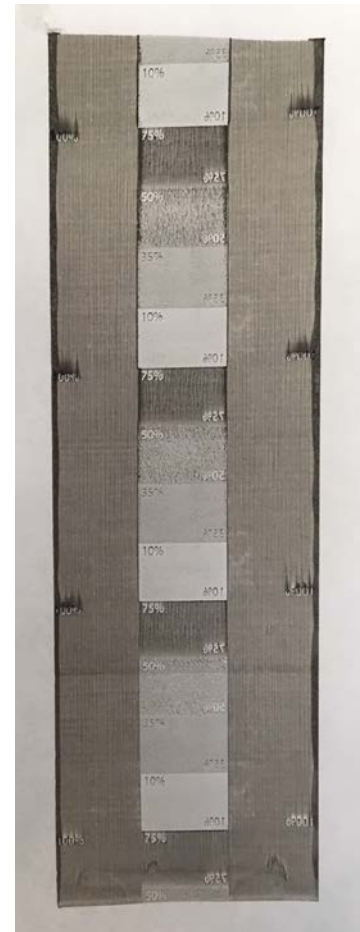


Figure 27 – Harper proof test, currency BC, 30% loading

G. Summary of Task 5 Activities and Outcomes (Economic and Environmental Analysis of Biochar vs. Carbon Black Based Inks)

- *Task 5: Conduct a comprehensive analysis to quantify the potential economic and environmental benefits of biochar-based inks relative to conventional carbon black-based inks, including any potential impact on indoor air quality. This Task includes a final project report and presentation at RIT to Staples personnel, or via videoconference (end of Task 5, Month 16)*

a. Potential Economic Benefits

According to the International Carbon Black Association (ICBA), CB is one of the top 50 industrial chemicals produced worldwide with 8.1×10^6 t manufactured annually. Approximately 9% (0.73×10^6 t) are utilized as pigments with the remainder in tire rubber and other applications. [8] According to industry consultants, CB's "...market volume will increase to more than 15 million tonnes by 2022." and "...the global carbon black market will surpass a value of \$25 billion by 2020, growing with a CAGR of over 4% during the 2015-2020 period." [29] A contact at Sid Richardson's sales, customer service, and technical service office in Akron, OH, said it is reasonable to estimate the average cost of CB to range between \$2.00 and \$2.50 lb⁻¹ or \$4.09 and \$5.51 kg⁻¹ (average \$4.80 kg⁻¹). Given that a typical black inkjet ink is comprised of 4-8% per volume pigment (as discussed in Task 2), a typical ink jet cartridge would therefore contain between .08 and .16 g or \$.00038 and \$.00077 worth of CB. According to the 2013 IBI industry research database, the average cost of BC in the U.S (n=17) is \$1.65 lb⁻¹ or \$3.63 kg⁻¹. [11] Therefore each ink cartridge would contain between \$.00029 and \$.00058 of BC, representing a 24.7% cost advantage over CB. Thus, hypothetically, if the estimated 0.73×10^6 t of CB used for ink that cost \$4.80 kg⁻¹ were simply replaced with BC that cost \$3.63 kg⁻¹ to manufacture, it could result in an annual savings to industry of \$854.1 million. This too could increase since "the global printing inks market is [forecasted] to reach \$23.9 billion by 2023. The rising importance of printed materials in various end-use industries such as packaging, labeling and advertising are likely to spike the demand for printing inks worldwide." [1]

b. Potential Environmental Benefits

The ability of BC to keep carbon in solid form and suppress its return to the atmosphere over a period of time is referred to as its 'recalcitrance'. The greater a BC's recalcitrance, the greater the length of sequestration benefit. As discussed in Task 2, studies have confirmed that a waste paper BC's recalcitrance is directly related to processing temperature and generally peaks at temperatures over 750°C as most of the 'loose' hydrogen and oxygen molecules are driven off

Energy demand and global warming potential of biochar and activated carbon. Values for energy demand indicate production energy unless noted otherwise (Bartocci et al., 2016; Bayer et al., 2005; Dang et al., 2015; Gabarrell et al., 2012; Gaunt and Lehmann, 2008; Hammond et al., 2011; Hjalila et al., 2013; Ibarrola et al., 2011; Johnsen et al., 2016; Meyer et al., 2012; Muñoz et al., 2007; Peters et al., 2015; Roberts et al., 2010; Sparrevik et al., 2013; Woolf et al., 2010b).

Material Type	Energy demand, MJ/kg	Global Warming Potential, kg CO ₂ eq/kg
Activated carbon (Virgin), hard coal	44 ^a	3, 3 ^a , 8, 11
Activated carbon, olive-waste	170	11
Activated carbon, Recycled		1.2
Activated carbon, Granular	79.8	9.3
Agroforestry biochar		-0.2
Anaerobic digestion biochar	1.1 ^{a,b}	-0.7
Barley straw biochar	1.1–2.2 ^b	-0.7 to -0.9
Biomass crops biochar (herbaceous)		-0.2
Biomass crops biochar (woody)		-0.2
Canadian forestry residue chips biochar	1.4–2.9 ^b	-0.9 to 1.1
Cardboard biochar	1.8 ^{a,b}	-0.1
Cattle manure biochar		-0.2
Cereals excluding rice biochar		-0.2 to -0.1
Corn Stover biochar	0.84, 1.5–3 ^a , 8	-0.7 to -0.8, -4 to -2
Dense refuse derived fuel	1.8 ^{a,b}	-0.3
Food waste biochar	1.3 ^{a,b}	-1.1
Forestry residue chips biochar	1.4–2.9 ^b	-1.3 to -1.1, -0.2 to -0.1
Green waste biochar	1.8 ^{a,b}	-1.1, -0.3
Maize cobs biochar		-0.1 to 0.1
Miscanthus biochar	1.4–2.9 ^b , 10	-3.5 to -3.1, -1 to -1.2, -0.6
Paper sludge biochar	1.1 ^{a,b}	-0.7
Pig manure biochar		-0.4
Poplar biochar	16	-1.2
Poultry litter biochar	1.1 ^{a,b}	-0.5, -0.2
Rice biochar		-0.4
Sewage sludge biochar	1.8 ^{a,b}	-0.8
Sugarcane biochar		-0.2
Switch grass biochar	1.5 ^a , 11	-2.8 to -2.5, -0.4 to 0
Wheat straw biochar	1.1–2.2 ^b , 8.3	-2.1 to -1.9, -0.9 to -0.7, -0.7
Whisky draff biochar	1.1 ^{a,b}	-0.8
Wood waste biochar	2.1 ^{a,b}	-1.3, -0.2
Yard waste biochar	3 ^a	-0.9

^a Estimated from figure.

^b Produced energy.

Figure 29 - CO₂eq kg⁻¹ GWP of various biochars (highlights added) [30]

resulting in high elemental carbon content and low H:C and O:C ratios. A common measurement of how much environmental impact is created or mitigated is expressed in terms of global warming potential (GWP) or CO₂ eq kg⁻¹. Creating BC from paper or cardboard waste is considered “carbon negative” due to the fact that more CO₂ eq is stored away rather than released to the environment when BC is made (Figure 29). This has far-reaching implications since, according to the EPA, over 25% of the MSW stream in the U.S. is comprised of paper and cardboard. [31] For Staples to understand the potential environmental benefits of creating BC-based inks from its own cardboard wastes compared with that of traditional CB, one needs to estimate the total amount of paper available from all Staples distribution facilities, how much BC can be created and multiply that amount by the GWP of cardboard BC. Though not presented here, it was calculated that Staples could ‘save’ a very significant amount of GWP annually by converting all its cardboard and paper waste to BC. However, that would preclude that material from being recycled into paper and cardboard again which itself has a positive GWP benefit compared to creating it from virgin material. It makes sense therefore, to make BC from the



Figure 30 – Indoor air quality ink testing apparatus

fraction of this continuous waste stream that cannot be recycled any further (i.e., the non-recyclable paper sludge that is simply disposed of) which has the added benefit of having one of the highest GWP sequestration values ($-0.7 \text{ CO}_2 \text{ eq kg}^{-1}$; Figure). In addition to large GWP sequestration potential, BC created from waste paper and cardboard can be considered more sustainable than conventional CB due to the lower energy input needed in its production. The pyrolysis of organic materials at temperatures under 500°C is generally exothermic (i.e., more energy is released than consumed), whereas the enthalpy of producing CB at 1650°C is strongly endothermic (i.e. more energy is consumed than released). An intriguing environmental extension of this research would be to determine if indoor/office air quality would benefit, be unchanged or be negatively affected if BC inkjet was substituted in an ink jet printer in lieu of traditional CB pigment. Though outside the scope of this present work, a sealed environmental test chamber setup for future experimentation to compare differences in volatile organic compound (VOCs) emissions between inks has been constructed (Figure 30).

H. Conclusions

The key takeaway from this research is that a new category of inks using BC pigments have been created that can be considered more fundamentally sustainable than current traditional CB offerings since their source of color are derived from waste products rather than fossil fuels. As with most goods however, those with the highest embodied energy are usually agreed to be the most effective or desirable and CB inks (which have been the most processed) are generally considered of the highest quality. This study attempted to strike a new balance between perceived quality and sustainability observing that not every application needs the ‘best’ ink available but rather for many purposes ‘good enough’ is more than adequate to achieve one’s desired printing goals. For example, is ‘perfectly’ 100% opaque generic brand advertising on the outside of cardboard shipping boxes completely necessary or would ‘less perfect’ 70% opaqueness have exactly the same desired effect but without any hidden embodied environmental costs? It seems for many non-critical, one time everyday use purposes that BC ink has its most significant potential to displace at least some of the CB that has become hidden in plain sight of society. Before that can happen however, more work in the lab needs to be performed to understand what is the ‘finest quality’ BC pigment that could possibly be made and how the environmental full-cost accounting of making that actually compares to CB. Lastly, since all cardboard manufactured today eventually either gets thrown away or recycled and then thrown away, being able to divert the unrecyclable portion from the landfill while perhaps eventually utilizing energy efficient microwave furnaces to convert that material to an upcycled, carbon-negative, value-added product appears the most promising way to achieve a more sustainable method of printing reminiscent of the pre-industrial era.

I. Acknowledgements

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Appendix A (Categories of Paper Waste)

Common Types of Paper Waste [32]

Uncoated Corrugated Cardboard usually has three layers. The center wavy layer is sandwiched between the two outer layers. It does not have any wax coating on the inside or outside. Examples include entire cardboard containers, such as shipping and moving boxes, computer packaging cartons, and sheets and pieces of boxes and cartons. This type does not include chipboard boxes such as cereal and tissue boxes.

Paper Bags means bags and sheets made from kraft paper. The paper may be brown (unbleached) or white (bleached). Examples include paper grocery bags, fast food bags, department store bags, and heavyweight sheets of kraft packing paper.

Newspaper means paper used in newspapers. Examples include newspaper and glossy inserts found in newspapers, and all items made from newsprint, such as free advertising guides, election guides, and tax instruction booklets.

White Ledger Paper means bleached, uncolored bond, rag, or stationery grade paper, without ground wood fibers. It may have colored ink on it. When the paper is torn, the fibers are white. Examples include white paper used in photocopiers and laser printers, and letter paper.

Colored Ledger means colored bond, rag, or stationery grade paper. When the paper is torn, the fibers are colored throughout. Examples include colored photocopy and letter paper. This type does not include fluorescent dyed paper or deep-tone dyed paper such as goldenrod colored paper.

Computer Paper means paper used for computer printouts. This type usually has a strip of form feed holes along two edges. If there are no holes, then the edges show tear marks. This type can be white or striped. Examples include computer paper and printouts from continuous feed printers. This type does not include white ledger used in laser or impact printers, nor computer paper containing ground wood.

Other Office Paper means paper used in offices other than ledger and computer paper. Examples include manila folders, manila envelopes, index cards, white envelopes, white window envelopes, notebook paper, ground wood computer paper, junk mail, and carbonless forms. This type does not include white ledger, colored ledger, or computer paper.

Magazines and Catalogs means items made of glossy coated paper. This paper is usually slick, smooth to the touch, and reflects light. Examples include glossy magazines, catalogs, brochures, and pamphlets.

Phone Books and Directories means thin paper between coated covers. These items are bound along the spine with glue. Examples include whole or damaged telephone books, yellow pages, real estate listings, and some non-glossy mail order catalogs.

Other Miscellaneous Paper means items made mostly of paper that do not fit into any of the other paper types. Paper may be combined with minor amounts of other materials such as wax or glues. This type includes items made of chipboard, ground wood paper, and deep-toned or fluorescent dyed paper. Examples include cereal and cracker boxes, unused paper plates and cups, goldenrod colored paper, school construction paper, butcher paper, milk cartons, ice cream cartons and other frozen food boxes, pulp paper egg cartons, unused pulp paper plant pots, and hard cover and soft cover books.

Remainder/Composite Paper means items made mostly of paper but combined with large amounts of other materials such as wax, plastic, glues, foil, food, and moisture. Examples include waxed corrugated cardboard, aseptic packages, plastic-coated paper milk cartons, waxed paper, tissue, paper towels, blueprints, sepia, onion skin, fast food wrappers, carbon paper, self-adhesive notes, and photographs.

Appendix B (HP 61 Particle Size Distribution & Zeta Potential)



Beckman Coulter LS Particle Size Analyzer

Page 1
30 Nov 2016 12:55

File name: R:\LS 13320\37379-10\61_Avg.\$av
File ID: 61_Avg.\$av
Sample ID: 61
Comment 1: HP Ink Jet Ink #61
Comment 2: ROCHESTER INSTITUTE OF TECHNOLOGY Chemist: AH
Optical model: Particle Technology Labs Carrier: Non-Aqueous PTL ID: 229746-10
Carbon BlackIPA.rf780d PIDS included

Volume Statistics (Geometric) 61_Avg.\$av

Calculations from 0.040 μm to 2000 μm

Volume:	100%	S.D.:	2.166
Mean:	15.83 μm	Variance:	4.692
Median:	17.61 μm	Skewness:	-0.646 Left skewed
Mean/Median ratio:	0.899	Kurtosis:	0.238 Leptokurtic
Mode:	21.70 μm		
d ₁₀ :	5.451 μm	d ₅₀ :	17.61 μm
		d ₉₀ :	39.41 μm

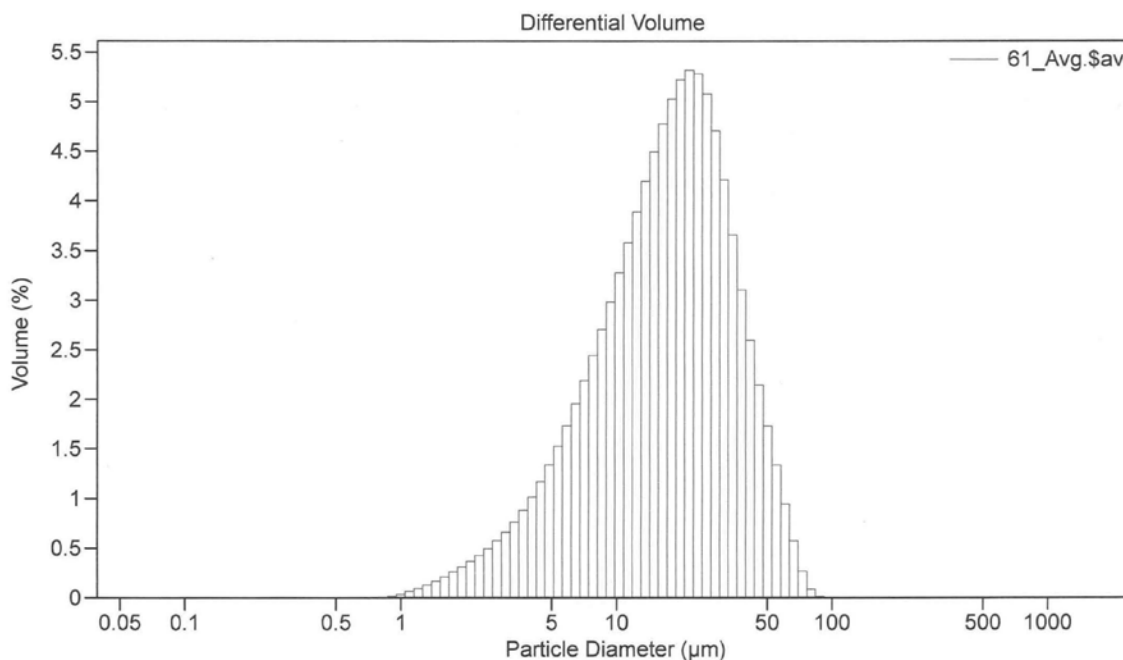


Figure 28 – Particle size distribution by laser diffraction, HP61 baseline ink

Att 2016-11-30
L. 2016-11-30

Size Distribution Report by Intensity

v2.0



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Sample Details

Sample Name: HP Ink Jet Ink #61, 61 - Average

SOP Name: mansettings.nano

General Notes: ROCHESTER INSTITUTE OF TECHNOLOGY

Chemist: NG

Particle Technology Laboratories PTL ID: 229747-10

File Name: 37379-10.dts

Dispersant Name: Water

Record Number: 12

Dispersant RI: 1.330

Material RI: 1.50

Viscosity (cP): 0.8872

Material Absorbtion: 1.000

Measurement Date and Time: Friday, December 02, 2016 9...

System

Temperature (°C): 25.0

Duration Used (s): 80

Count Rate (kcps): 140.2

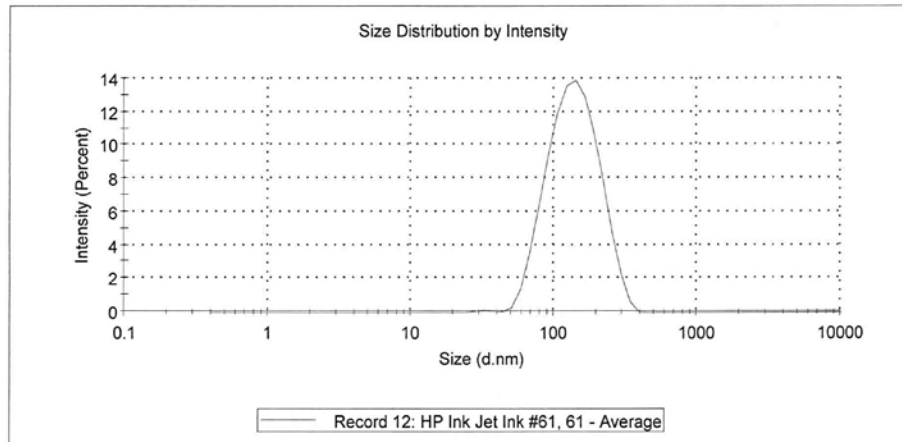
Measurement Position (mm): 4.65

Cell Description: Disposable sizing cuvette

Attenuator: 7

Results

	Diam. (nm)	% Intensity	Width (nm)
Z-Average (d.nm): 125.9	Peak 1: 146.4	99.6	56.85
Pdl: 0.128	Peak 2: 34.99	0.4	5.049
Intercept: 0.947	Peak 3: 0.000	0.0	0.000



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Zetasizer Ver. 7.11
Serial Number : MAL500684

NG 2016-12-02
2016-12-02 (RF)
2016-12-05
File name: 37379-10
Record Number: 12
02 Dec 2016 9:33:41 AM

Figure 29 - Particle size distribution by dynamic light scattering, HP61 baseline ink

Zeta Potential Report

v2.3

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Sample Details

Sample Name: HP Ink Jet Ink #61, 61 - Average

SOP Name: mansettings.nano

General Notes: ROCHESTER INSTITUTE OF TECHNOLOGY

Chemist: NG

Particle Technology Laboratories PTL ID: 229747-10

File Name: 37379-10.dts

Dispersant Name: Water

Record Number: 6

Dispersant RI: 1.330

Date and Time: Friday, November 18, 2016 2:06:...

Viscosity (cP): 0.8872

Dispersant Dielectric Constant: 78.5

System

Temperature (°C): 25.0

Zeta Runs: 12

Count Rate (kcps): 47.1

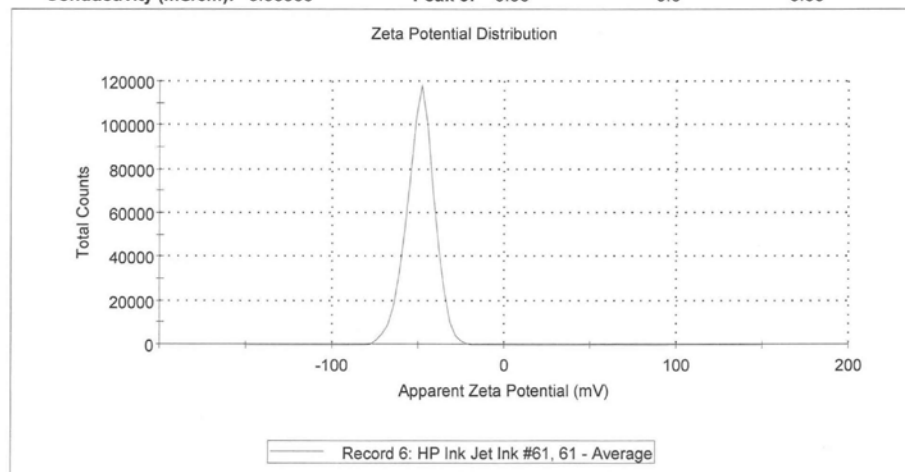
Measurement Position (mm): 2.00

Cell Description: Clear disposable zeta cell

Attenuator: 11

Results

	Mean (mV)	Area (%)	St Dev (mV)
Zeta Potential (mV): -48.8	Peak 1: -48.8	100.0	8.25
Zeta Deviation (mV): 7.98	Peak 2: 0.00	0.0	0.00
Conductivity (mS/cm): 0.00565	Peak 3: 0.00	0.0	0.00



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Zetasizer Ver. 7.11
Serial Number: MAL500684

NG 2016-11-18
RUC 2016-11-21

File name: 37379-10.dts
Record Number: 6
18 Nov 2016 2:12:48 PM

Figure 30 – Zeta Potential, HP61 baseline ink

Appendix C (SEM Images and X-ray Fluorescence (XRF) Analyses)

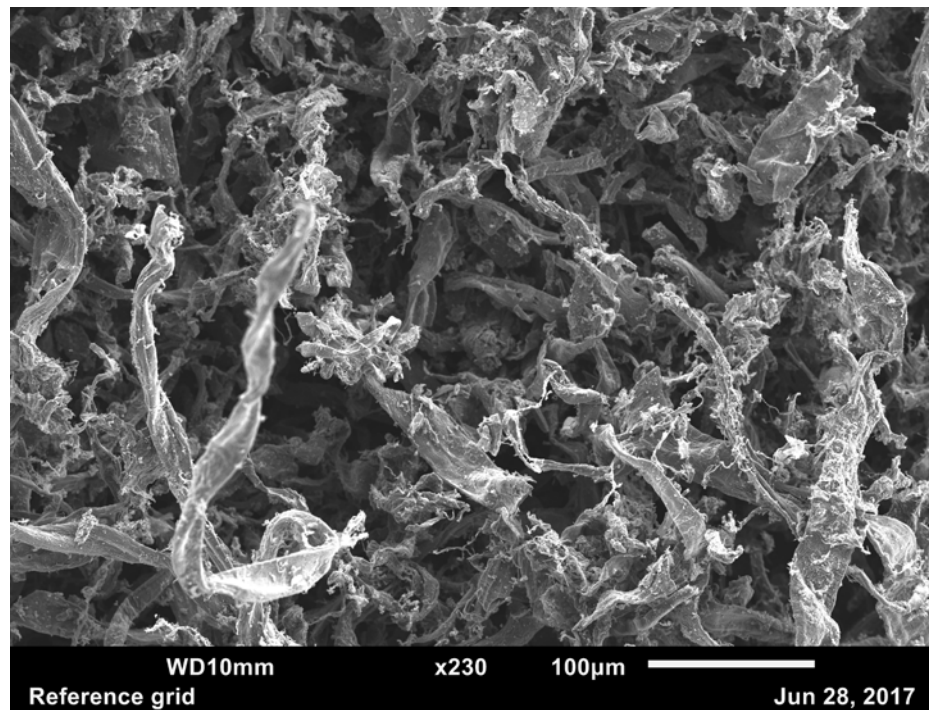


Figure 31 – Staples cardboard biochar 1600 °C with clearly visible cellulose fibers

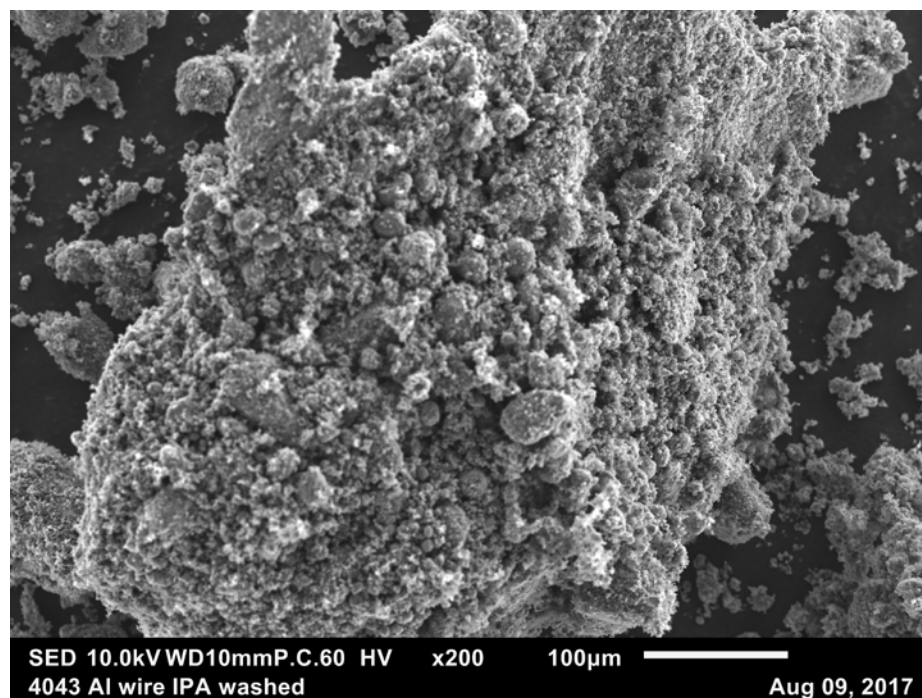
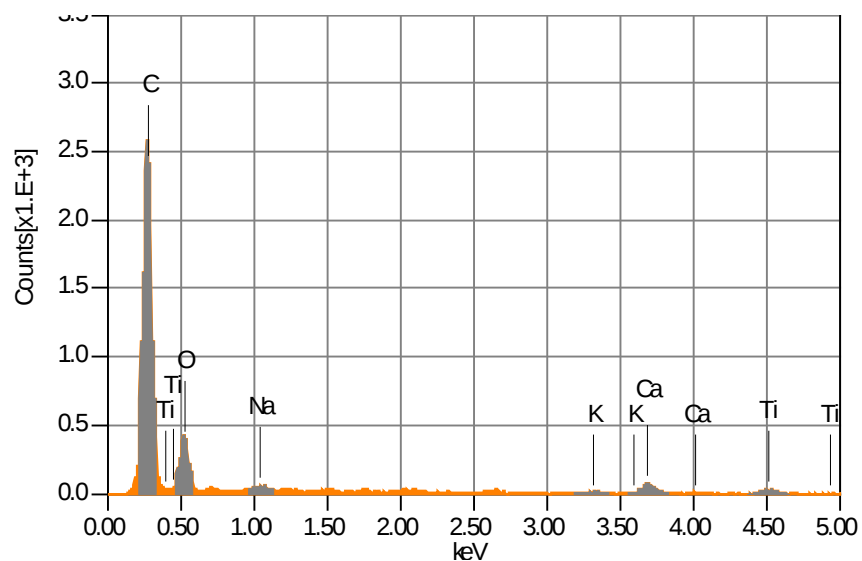
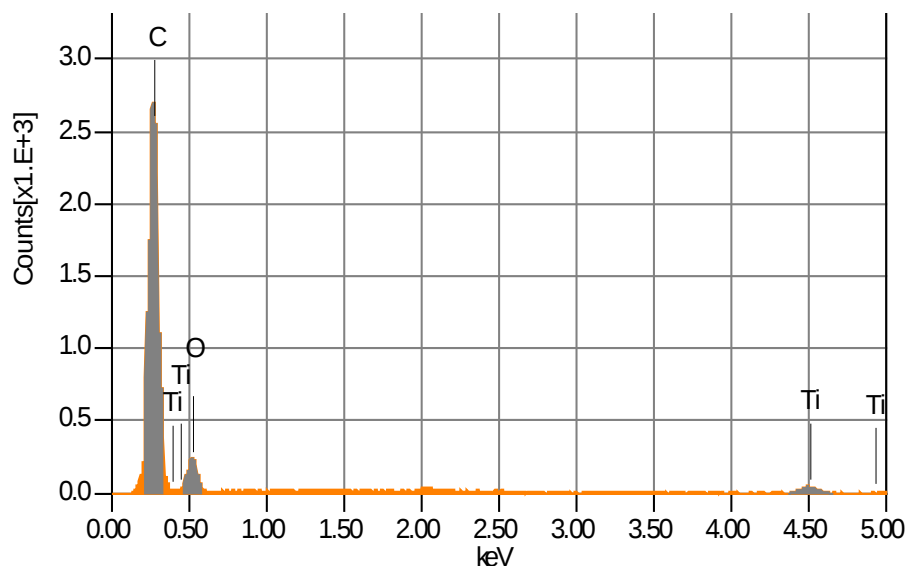


Figure 32 - Staples cardboard biochar, 200x magnifications



Formula	mass%	Atom%	Sigma	Net	K ratio
C	63.99	75.61	0.07	55776	0.0270081
O	22.26	19.74	0.20	9589	0.0144153
Na	0.50	0.31	0.06	758	0.0008821
K	0.93	0.34	0.10	632	0.0024466
Ca	6.01	2.13	0.18	3734	0.0165965
Ti	6.31	1.87	0.22	2023	0.0143746
Total	100.00	100.00			

Figure 33 – Elemental XRF analysis of currency biochar processed at 1600 °C (pre-functionalization)



Elements	mass%	Atom%	Sigma	Net	K ratio
C	75.00	83.83	0.08	60640	0.0293634
O	16.39	13.76	0.19	5826	0.0087581
Ti	8.61	2.41	0.27	2455	0.0174407
Total	100.00	100.00			

Figure 34 – Elemental XRF analysis of currency biochar processed at 1600 °C (post-functionalization)

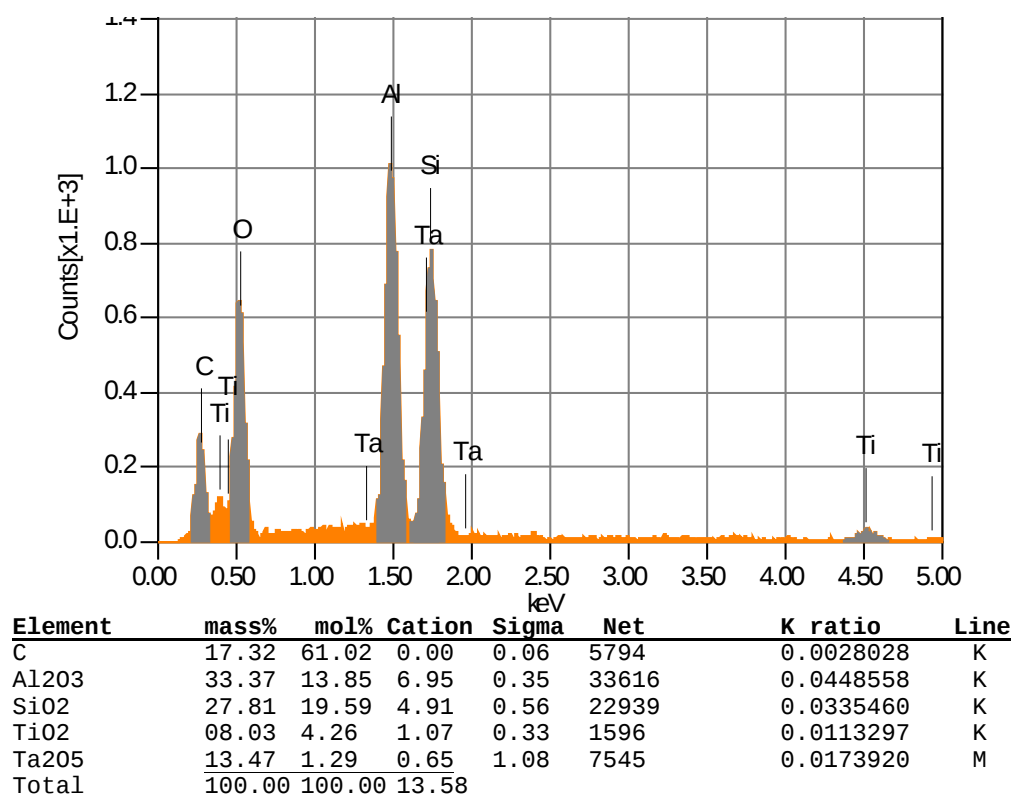


Figure 35 – Elemental XRF analysis of aluminum contamination from high alumina crucibles

Appendix D (Additional Print Image)

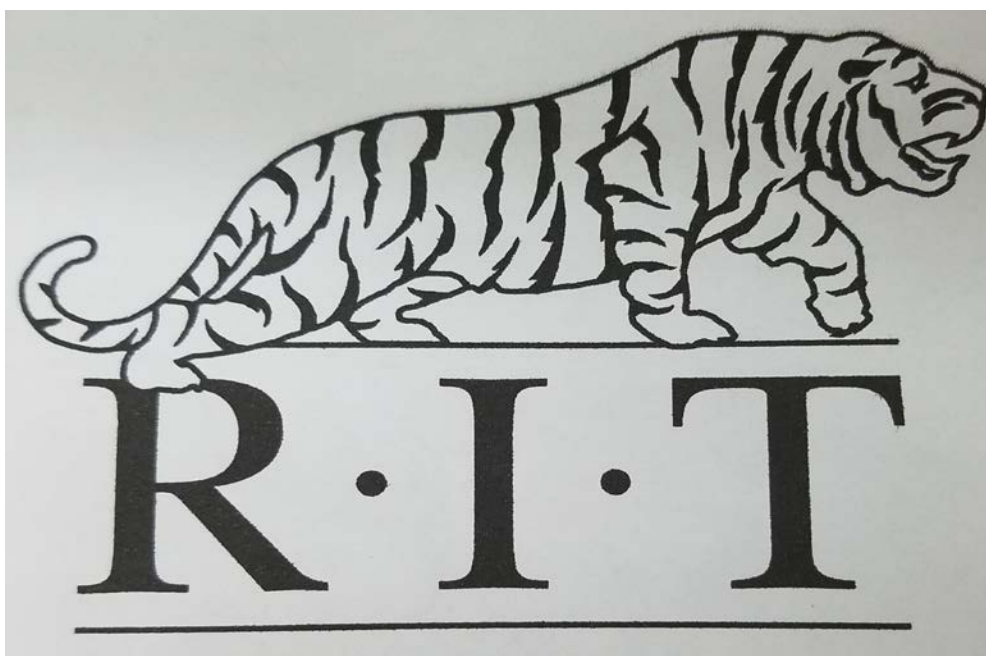


Figure 36 – Fuji Dimatix inkjet print on uncoated printer paper using water-based synthetic HP61 ink created with SR 201 CB

Appendix E (PMAL Ink Testing)



Print and Materials Analysis Lab (PMAL) Services and Equipment

Services

Comprehensive Evaluations

- Evaluations of paper, ink, toner, fountain solution, plate, blanket, and other media
- Comparative print performance analysis
- Product audits
- Defect analysis
- Competitive benchmarking
- Product/grade development
- Customized corporate-sponsored studies and development activities
- Press simulation

Print Performance and Evaluation Criteria

Printability

- Dot analysis: gain, shape, roundness, spacing, placement
- Contrast resolution Index
- Color gamut
- Gray scale densities
- Print gloss, delta gloss
- Print non-uniformity
- Print mottle
- Back trap mottle
- Banding (inkjet)
- Banded multiscreen anilox or single screen anilox (flexographic)
- Cell skip (gravure)
- Color-to-color bleed: black line over yellow background (inkjet)
- Feathering (inkjet)
- Folder crack test (web)
- Hexacrome, Hi-Fi (sheetfed)
- Ink trapping
- Modulation transfer function
- Pick count
- Light fastness

Runnability

- Contaminant test: slitter dust, milking, linting, picking (web, sheetfed)
- Wet pick vs. dry pick
- Back trap dry pick (sheetfed, web)
- Blister resistance, fiber rise (web)
- Chill marking (web)
- Ink and water balance window (web, sheetfed)
- Ink mileage (web)